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Growth and Survival Rate of Nearshore Fishes in Lake Michigan

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Executive Summary

Research described in this report focuses on Illinois waters of Lake Michigan and provides essential information for the Illinois Department of Natural Resources (IDNR) to better understand factors contributing to nearshore fish community assemblages in a spatial and habitat related context. Information presented herein expands limited data and directly aids fisheries management efforts. This report describes results obtained during 2009 field season and marks the second year of major changes to the project, which included changing sampling locations, expanding sampling sites to include different habitat types, and expanding sampling techniques to collect juvenile fish.

Data analysis from field sampling conducted in 2010 is ongoing and lab processing is not complete. As such, a complete reporting of data collected during the 2009 sampling season is presented, covering data from Segments 12 and 13. Further, some objectives are based on long term data collection and insights will become clearer as results accrue through future sampling; therefore, results for each objective may not be specifically discussed in this report. Below, we present the study objectives and several research highlights.

Study 101: Quantify seasonal abundance, composition and growth of juvenile fishes

1. Alewife was the most abundant fish at Dead River (DR), but catches declined through the summer. Annual alewife CPE was lower at Chicago (S2) and Highland Park (M2), but monthly CPE increased each month from June through August.
2. Yellow perch CPE was highest at M2, followed by S2. In general, monthly catch rates fluctuated at all locations.
3. Round goby CPE was highest at M2 and S2, with highest catches in June and July. At DR, CPE was highest in the fall.
4. Size of fish captured in the small-mesh gill nets ranged from 43-230 mm, giving us a variety of juvenile age classes for the different fish species.

Study 102: Quantify nearshore zooplankton abundance and taxonomic composition

1. Annual mean zooplankton density (crustaceans and rotifers) ranged from 6.94 – 9.87 ind/L and did not differ between the three locations.
2. Rotifers and nauplii were the most abundant taxa at DR and M2. Bosminidae were more abundant at S2 than the other two locations.

Study 103: Estimate relative abundance and taxonomic composition of benthic invertebrates

1. Mean annual density of benthic invertebrates collected in cores ranged from 567 ± 437 ind/m^2 at DR to 2931 ± 2773 ind/m^2 at M2.
2. Densities of invasive mussels were very small, except for a peak density in September at S2. Annelids and chironomids were the most abundant taxa at most sites.
3. Densities from benthic cores at the 7 m sites were higher than the 3 and 5 m depths at M2 and S2.
4. No rocks were ever collected at the very sandy DR site. Taxa diversity was higher on M2 rocks compared to those collected at S2.

<u>Study 104:</u> Explore multivariate patterns in nearshore fishes and prey communities

1. Zooplankton communities at the three locations were very similar. Bosminidae were a main contributor to the small differences observed.
2. Invertebrate communities in core samples differed slightly between locations; DR was most different from the other two locations.
3. Analysis of 22 prey taxa in early summer diets showed clustering based on fish species only. Yellow perch, round goby and spottails had very different diets in June and July.

Introduction

Great Lakes management strategies are shifting away from an individual species perspective towards the broader and more comprehensive fish community approach. Thus in 2008 we began focusing sampling on juvenile fish of varying age classes in different habitat types across seasons, to better understand fish community composition, seasonal habitat use, habitat overlap, diet overlap, and interactions of native species with invasive ones.

An overlap in the distribution of species (e.g., alewife, *Alosa pseudoharengus* and rainbow smelt, *Osmerus mordax*) may reduce the fitness of one or both species if they compete for limited resources (Stewart et al. 1981). For example, food quantity and timing of food availability are critical determinants of first-year growth and survival of fish (Miller et al. 1988). Results of Confer et al. (1990) and Miller et al. (1990) suggest that the decline of bloaters and other native planktivores in Lake Michigan during the 1960s and 1970s may have been largely the result of shifts in zooplankton composition associated with intense planktivory by alewife. Other Great Lakes native species have experienced strong negative effects of high alewife abundances, including yellow perch, deepwater sculpins, emerald shiners, burbot and lake trout (Madenjian et al. 2008). Alewife is just one of many invasive species that have impacted the ecology of Lake Michigan. Other pelagic invaders include rainbow smelt, and two spiny Cladocerans (*Bythotrephes* and *Cercopagis*). Zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*) and round goby (*Neogobius melanostomus*) have dramatically changed the benthic community in recent years (Kuhns and Berg 1999; Vanderploeg et al. 2002; Barton 2005).

Changes caused by invasive species can affect diet and competitive interactions of Lake Michigan fish. Hrabik et al. (2001) found YOY rainbow smelt and yellow perch competing for zooplankton and their diets overlapped more than 45%. Round goby < 70 mm consume a variety of benthic invertebrates, very similar to small yellow perch and other native fish (Vanderploeg et al. 2002). Stomach analysis from 2000-2006 in southwestern Lake Michigan revealed that diets of age-0 yellow perch in August and September overlapped with alewife ≤ age 1 and age-0 rainbow smelt (Creque et al. 2007).

Diet overlap and competition can also occur between varying age-classes of the same species or congeners. In a field study of yellow perch, annual dietary overlap between consecutive year classes was above 68% for both taxonomic and prey size categories (Keast 1977). Persson (1983) found high overlap values between age 2 and 3 European perch (*Perca fluviatilis*), which with low prey resources could indicate intraspecific competition. Data from southwestern Lake Michigan indicated that yellow perch diets overlapped in October, when both YOY and age-1 perch switched primarily to amphipods (Creque et al. 2007). Although this shift reduced yellow perch diet overlap with spottails and alewife, it may increase intra-specific competition, especially if amphipods declined. If *Diporeia* abundances collapse in Illinois waters, as seen on the eastern side of Lake Michigan (Nalepa et al. 1998; Madenjian et al. 2002), it could have a severe impact on age-0 yellow perch. Competitive interactions between two successive age-classes could result in reduced growth rates of younger fish thus reducing their over-winter survival (Persson 1983). Both plankton and benthic resources have declined since the high yellow perch abundances of the 1980s. Thus, increased competition due to declining prey levels may be the reason for lack of back to back successful year classes of yellow perch since the late 1980s. Continuous expansion of round goby northward and their recent establishment in the Waukegan area could create additional competitive pressure through diet overlap for young cohorts of yellow perch.

Species diversity tends to increase with increasing habitat complexity (Keast and Eadie 1985; Danehy et al. 1991; Pratt and Smokorowksi 2003). Within the Great Lakes, there are generally large homogenous regions of soft, sandy substrate for nearshore communities; regions of structured/hard bottoms are few but disproportionately important habitats (Danehy et al. 1991; Janssen et al. 2005). The critical importance of such habitat was highlighted by Danehy et al. (1991), who found that yellow perch captured at cobble sites grew faster than those collected at sandy sites in Lake Ontario. Winnell and Jude (1987) collected over 190 species of invertebrates from rocky, littoral habitats showing richness and diversity of food for fish in such areas.

There are a large number of studies of pelagic productivity, but few focus on the littoral zone (Vadeboncouer et al. 2002). There are many more studies on soft bottom habitats because of their ease of sampling, and the lack of data on hard substrates prevents complete understanding of the ecosystem (Winnell and Jude 1987; Janssen et al. 2005). Rocky nearshore habitats are critical for many fish and invertebrate species, and steps must be taken to increase our knowledge of the community interactions at these areas.

Our objectives for this study are continued monitoring of zooplankton, invertebrates, fish, and fish diets through a sampling scheme to include additional habitat types. The use of more effective sampling methods will help develop a better understanding of the combined influence of biotic and abiotic factors on fish recruitment in southwestern Lake Michigan. Multiple years of data will allow us to explore multivariate patterns in nearshore fish communities and yellow perch growth in relation to habitat differences, prey availability, and invasive species. This information will provide key insights into nearshore areas with the best growth and survival potential for both native and non-native fish.

Study site

Segment 13 marks the second season with sampling sites slightly different than in previous segments to reflect the new objectives. Sampling associated with all studies described below occurred at three selected locations along the Illinois shoreline of Lake Michigan during June-October. The Illinois shoreline of Lake Michigan is naturally divided into three distinct geologic regions: Zion beach-ridge plain, Lake Border Moraines bluff coast, and Chicago/Calumet lake plain (Chrzastowski and Trask 1995). Nearshore bottom substrate within each of these areas is unique. More specifically, we sampled at a location in the Zion beach-ridge plain, 3.7 km north of Waukegan Harbor at the mouth of the Dead River (DR; Figure 1). An area in southern Illinois waters, located between Chicago's Rainbow Park water treatment plant and 59th Street Harbor (S2), represents the Chicago/Calumet lake plain area. The DR and S2 locations were also sampled in Segments 1 – 11. The Lake Border Moraine Bluff coast region is represented at a location off of Highland Park, IL (M2). This location was part of the preliminary sampling in Segments 10 and 11.

Methods

Sampling was conducted at each location twice a month, weather permitting, from June through October. Weather conditions did not allow sampling in October during the 2009 sampling season. Within each location we established a grid of nine sites covering an area of approximately 1.5 km^2. There are three transects perpendicular to shore with sites at roughly 3, 5 and 7.5 meters water depth (Figure 1). All three water depths are sampled during each outing, with specific site selection chosen by random draw with replacement. On each sampling date, ambient water temperature and secchi disk measurements were recorded. Continuously recording temperature probes to monitor water temperatures throughout our sampling season are located at a site south of Waukegan Harbor (T4), which is also sampled as part of related project F-123-R, and at the artificial reef in Chicago (Figure 1).

Study 101: Quantify seasonal abundance, composition and growth of juvenile fishes

Job 101.1: Quantify abundance and composition of juvenile fishes

Juvenile fish were sampled using monofilament small-mesh gill nets. These nets consist of 33-foot panels of 0.31, 0.50, 0.75, and 1.0-in stretch mesh. Nets were fished at 3, 5 and 7.5 meter depths at each location and set for 2-4 hours during the day. Fish in each net were identified to species and counted; a subsample was preserved for laboratory analysis and the remaining fish were measured for length and returned to the lake.

Job 101.2: Diet and growth analysis of juvenile fish

Fish preserved in small-mesh gill net subsamples were later analyzed in the laboratory. Each fish was assigned a unique identification number; length was measured in mm and weight in grams. Fish were dissected to remove stomachs and otoliths. During diet analysis prey taxa were identified to the lowest practical level and length measurements were taken on up to 20 organisms of each taxon in good condition. Otoliths were placed in individual vials for later reading.

Job 101.3: Data analysis and reporting

Data were entered and checked in Access databases. Analysis was performed with SAS software. Catch per effort in small-mesh gill nets was calculated as number of fish per hour set. CPE was analyzed as both total and mean.

Study 102: Quantify nearshore zooplankton abundance and taxonomic composition

Job 102.1: Sample zooplankton

Duplicate zooplankton samples were taken at the 3, 5 and 7.5 meter sites during June-September. At each site a 63-µm mesh 0.5-m diameter plankton net was towed vertically from 0.5 m above the bottom to the surface. Sampling the entire water column generates a representative sample of the zooplankton community composition and abundance. Samples were stored immediately in 5% sugar formalin.

Job 102.2: Id and count zooplankton

In the lab, samples were processed by examining up to three 5-ml subsamples, taken from adjusted volumes that provided a count of at least 20 individuals of the most dominant taxa. Zooplankton were enumerated and identified into the following categories: cyclopoid copepodites, calanoid copepodites, copepod nauplii, rotifers, cladocerans to genus (*Daphnia* to species), Macrothrididae spp., Sididae spp., and *Dreissena sp.* veligers. Uncommon and exotic taxa were noted.

Job 102.3: Data analysis and reporting

Zooplankton data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of zooplankton abundance and species composition were run using SAS version 9 software. For this report, total zooplankton includes crustaceans and rotifers. *Dreissenid* veligers are analyzed separately.

<u>Study 103:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates

Job 103.1: Sample in soft sediments

SCUBA divers collected benthic invertebrates once a month at the 3, 5 and 7.5 meter sites at each location using a 7.5-cm diameter core sampler. Four replicate samples from the top 7.5 cm of the soft substrate were collected and preserved in 95% ethanol (Fullerton et al. 1998). When soft to sandy substrate sediments were limited, especially at M2 and S2, sample depth was reduced to 3.75 cm.

Job 103.2: Sample on rocky substrates

While diving for benthic cores, SCUBA divers randomly selected four baseball sized rocks and placed them in individual Ziploc bags. If there were no suitable rocks in the vicinity, they swam approximately 100 meters to look for any. If none were found, the site was noted as having no rocks.

Job 103.3: Id and count invertebrates

In the lab, benthic core samples were sieved through 363-µm mesh screens to remove sand. Organisms were sorted from the remaining sediment debris. Organisms were identified to the lowest practicable level, typically to genus; total length (mm) and head capsule width were measured for each individual. All taxa were enumerated and total density estimates were calculated. Rocks collected were carefully scraped and rinsed to remove attached organisms. Taxa were identified and measured using the same techniques as with cores. The rocks were labeled with a sample number for later calculation of surface area.

Job 103.4: Data analysis and reporting

Data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of benthic invertebrate abundance and taxa composition were run using SAS version 9 software.

<u>Study 104:</u> Explore multivariate patterns in nearshore fishes and prey communities

Job 104.1: Explore multivariate patterns

Percent composition by density was analyzed for benthic core and zooplankton data to give an indication of community patterns by depth and location. Data were square root or fourth root transformed and analysis was performed in Primer-E multivariate software.

Job 104.2: Impact of round goby on yellow perch

Diet data from a subset of fish collected in June and July 2008 were analyzed for similarity trends. These fish were not reported on in the Segment 12 report. Percent composition by number in individual stomachs was determined for 22 prey taxa. Mean percent composition for each fish group was then calculated for each month and location combination. This data was analyzed in Primer-E software using cluster, non- metric multi-dimensional scaling (NMDS), similarity percentages (SIMPER), and analysis of similarity (ANOSIM) methods.

Job 104.3: Report preparation

Multivariate analyses of 2008 and 2009 data were included in this report.

Results

Segment timing of this project runs from August through July and thus one field season is covered by two consecutive segments. However, to draw meaningful conclusions and present data in the most logical format, results are presented for the entire 2009 sampling season (June – September) which includes data collected in Segment 12 and Segment 13. Differences in number of samples collected at the three locations result from occasional weather related cancellations of sample outings, equipment issues, and boat repairs.

Study 101: Quantify seasonal abundance, composition and growth of juvenile fishes

Job 101.1: Quantify abundance and composition of juvenile fishes

A total of 22, 21 and 21 small-mesh gill nets were set at DR, M2 and S2 respectively. Annual mean catch rates (fish/hour) were 8.4 ± 9.1, 10.6 ± 10.0, and 7.3 ± 10.2 and showed relatively high variability (Figure 2a). There were some fish community differences between locations. Dead River had the highest annual CPE for alewife (91 fish/hour), higher spottail shiner CPE, and lower round goby CPE compared to the two south locations. Yellow perch and round goby were most abundant at M2 and S2, the two rockier locations, with CPEs slightly higher at M2 (Figure 2b). Alewife annual CPE declined from north to south. Bloater was not collected at S2. Other fish taxa were very rare at DR and S2 and not collected at M2 locations.

Most fish species had seasonal differences in abundance within and between locations. Alewives were caught at all 3 locations in June - August (Figure 3); however their numbers declined during this time period at DR and increased at M2 and S2. No alewives were captured at S2 in September. Spottail shiners were captured in all 4 months at DR, but sporadically at the other locations. Round goby catches were higher during June and July than August-September at the two rocky sites. Yellow perch were captured in moderate numbers (4 - 25 fish/hour) during all months at S2 and M2, but were caught at DR only in July and September (2-6 fish/hour) (Figure 3).

Spottail shiners were the only species with a consistent pattern among locations in CPE when analyzed by water depth over the sampling season; spottail CPE was highest at the 5 m depth sites. Round goby CPE at M2 and S2 7.5 m sites was at least 3 times higher than the shallow 3 m depth (Figure 4). Alewife CPE at DR and M2 was highest at 3 m, but the opposite pattern occurred at S2, where alewife CPE was highest at 7.5 m. Yellow perch CPE was lowest at 3 m for all locations and highest at 7.5 m for M2 and S2.

Job 101.2: Diet and growth analysis of juvenile fish

We caught a wide range of fish sizes in the four paneled small-mesh gill nets. The smallest fish captured were generally round goby, although we did catch alewife as small as 56 mm and yellow perch as small as 52 mm total length (Table 1). With the exception of gobies, fish that would be considered young of the year were not caught until August. Too few young of the year fish were caught in September and October to make any conclusions regarding differences or similarities in growth rate between the three locations at this time.

A subset of stomachs of the four most common species, yellow perch, alewife, spottail shiners and round goby, from June and July 2008 samples have been analyzed; 256 of these contained identifiable prey items. Mean size of yellow perch, alewife and spottail shiners whose diets were analyzed ranged from 105 – 122 mm; mean size of round gobies was smallest at 78 mm (Table 2). Number of prey items per stomach in alewife, which consumed primarily zooplankton, was higher by several orders of magnitude compared to the other 3 species (Figure 5a). Frequency of occurrence for zooplankton was lowest in spottail shiner stomachs. Prey items of yellow perch and round goby were relatively similar, with the exception of Dreissenid mussels, which were consumed by 14% of round goby but no yellow perch (Figure 5b). Chironomids were the most common prey category and were consumed by over 80% of all fish analyzed.

Job 101.3: Data analysis and reporting

Data was entered and checked into Access databases. SAS statistical software was used to analyze data and generate reports for inclusion in this report.

<u>Study 102:</u> Quantify nearshore zooplankton abundance and taxonomic composition

Job 102.1: Sample zooplankton

A total of 42 zooplankton samples were collected from each location. Replicate samples were collected at the 3, 5 and 7 m sites.

Job 102.2: Id and count zooplankton

Mean annual zooplankton densities were low in 2009 and did not differ among locations. Annual mean density (ind/L), including rotifers, was 9.9 ± 13.7 at DR, 9.4 ± 9.7 at M2 and 6.9 ± 8.3 at S2. Densities were lowest in June at all locations (Figure 6). August densities were three times higher at DR compared to S2 and M2.

Bosminidae, calanoid copepods, copepod nauplii and rotifers were the most common taxa collected. However, there were seasonal variations in composition and abundance patterns among the three locations. Bosminidae did not appear in noticeable numbers at any location until July; abundance was highest in September at all locations except DR (Figure 6). Nauplii density was relatively consistent through the sampling season at M2 and S2, but showed a peak density in August at DR. At all locations, rotifer densities were lowest in June and October.

In general, monthly mean density was similar at all depths at each location. Taxa composition among depths was also very similar. Densities in August at DR showed the largest difference between depths. Zooplankton densities were usually highest at 7 m depths, although this difference was not significant. The exception was September at DR, which had a peak at 3 m, as it did in 2008 (Figure 7).

Densities of dreissenid veligers were low compared to years past; with peak monthly mean densities below 20 ind/L (Figure 8). Annual density was highest at S2 (5.4 ± 11.9) and lowest at M2 (1.1 ± 2.5). In general, density across depths at all locations was similar, with the largest differences occurring in August when densities were lowest at the 5 m sites (Figure 8). Highest mean density occurred at the 7 m sites in August, where DR and S2 were the main contributing locations.

Job 102.3: Data analysis and reporting

Data were entered and checked in Access databases. Data were analyzed with SAS software for inclusion in this report.

<u>Study 103:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates

Job 103.1: Sample in soft sediments

We collected a total of 115 benthic cores in the 2009 field season. No cores were collected in June at M2 and August at DR due to boat repair, weather, and diver issues. Cores were not collected in October due to deteriorating weather conditions.

Job 103.2: Sample on rocky substrates

Dead River is a very sandy location, and no rocks were ever observed on SCUBA dives. Thus there are no samples from rocky substrates for this location. A total of 20 rocks were collected at M2; only one of the three meter sites had several rocks. Rocks were also never observed at the 3 meter sites at S2. Rock availability was scattered at S2-5 and 7 meter sites and a total of 14 were collected. Often there were larger rocks or ones that were so embedded in the clay they could not be removed.

Job 103.3: Id and count invertebrates

Mean annual density of benthic invertebrates collected in cores was lower at DR (568 ± 437 ind/m^2) compared to M2 and S2 (ind/m^2 >2800) ($F=3.11$, $P<0.05$). Patterns in seasonal density differed somewhat (Figure 9). Dead River densities were highest in June, but still lower than S2. Invertebrate densities at S2 were similar June through August and peaked in September (Figure 9). M2 densities declined slightly from July through September.

There were also differences in taxa composition amongst the three locations. Abundance of invasive mussels (primarily *Dreissena bugensis*) was lower than in previous years and provided a major contribution to the community only at S2 (Figure 9). Percent composition of native mussels and ostracods was highest at DR. Chironomid densities were significantly higher at M2 compared to DR. Densities of annelids were highest at M2 except during September when they were more abundance at S2. Amphipods were collected in low densities at all locations. Nematods were much less abundant at DR compared to the two locations south.

There were some differences in taxa composition and abundance when looking at site depth for each location across the sampling season. For M2 and S2, annual mean invertebrate densities were highest at the 7 m sites and lowest at the 3 m sites, while 5m sites had the highest annual densities at DR (Table 3). No one taxa showed a consistent pattern in percent composition by depth at any location. Annelids were most common at 3m at M2 and S2, but lowest at 3m at DR. Chironomids on the other hand had highest percent composition at the 3 m depths for DR and S2, but for 5 m sites at M2. Nematods were less common at 7 m for DR and M2, but highest at S2 7 m sites. Percent composition of native mussels declined with increasing water depth at S2, but increased at DR.

Thirty-one taxa were identified on M2 rocks and 17 on S2 rocks. Oligochaetes, chironomid larvae, juvenile Pelecypoda, and *Dreissena bugensis* were the most abundant taxa on the hard substrate at M2 (Table 4). Juvenile Pelecypoda, *Dreissena bugensis*, and Nematods were most abundant on S2 rocks. S2 had twice the number of invasive mussels on rocks and no native snails were found. Amphipod taxa were collected in varying numbers at both locations; Gammaridae and *Echinogammarus ischnus* were more common at S2 while *Hyalella azteca* were collected at M2 but not S2. Mayflies and isopods were found in low numbers at M2, and none were found at S2.

Job 103.4: Data analysis and reporting

Data from benthic cores and rock collections were entered and checked in Access databases. Analysis was run using SAS software and compiled for this report.

<u>Study 104:</u> Explore multivariate patterns in nearshore fishes and prey communities

Job 104.1: Explore multivariate patterns

Water temperatures from our profile sampling indicated a relatively cool year at all 3 locations. Highest recorded water temperatures at DR and M2 actually occurred in September, while S2's highest recorded temperatures were in June (Figure 10). Water temperature differences among site depths were relatively minor at all three locations, but most noticeable at DR, especially for bottom temperatures. Large differences on the same date between surface and bottom temperatures also occurred at all locations. Total gill net CPE by date and location had no significant correlation with mean bottom temperature at each location. Individual species CPE had a weak positive correlation with bottom temperature for rainbow smelt, spottail shiners, yellow perch and the "other" species category with correlation coefficient (r) ranging from 0.36-0.47.

Primer analysis of six zooplankton taxa categories indicated very similar zooplankton communities at all three locations and no annual differences between 2008 and 2009 communities. Multi-dimensional scaling provides an illustration of the relationship between the zooplankton community for the locations/depths and years. The sites at S2 generally group together the closest (Figure 11). Differences that did exist were highest between DR and S2 (17% dissimilarity), with Bosminidae a main contributor (Figure 11). No community differences were observed when using depth as a factor.

Benthic core data in 2008 and 2009 were analyzed for community patterns using the eight general taxa categories from the previous benthic core analysis. Using two years of data gave us several more permutations to run in analysis of similarity (ANOSIM), however numbers are still low and thus results must be viewed with caution. Global r was 0.47, indicating that communities at the 3 locations were moderately dissimilar. Benthic communities were most different between DR and M2 (global r = 0.7, 39% dissimilarity). Cluster analysis showed that the M2 sites tended to cluster together on the left side of the graph, while DR and S2 were scattered on the right side (Figure 12). Taxa contributing the most to community dissimilarity amongst all three locations were native mussels, dreissenids, and ostracods (Figure 13). No community differences were observed when using depth as a factor.

Job 104.2: Impact of round goby on yellow perch

Annual mean CPE of round goby and yellow perch was very similar and did not differ between M2 and S2 (Figure 2). However, round goby and yellow perch CPE varied seasonally; round goby CPE was highest in June and July while yellow perch CPE was lowest in June (Figure 3). A variety of multivariate tests were run on 22 prey taxa in the June and July diets of spottails, round goby, yellow perch and alewife to look for potential diet similarities/overlap. The global r of the ANOSIM test was 0.9 ($p < 0.01$), indicating these 4 fish consumed different prey taxa during these 2 months. Although there is only one year of data, clustering does show distinct groupings by species (Figure 14). Alewife diets were the most dissimilar to all other species (73-89% dissimilar), with chironomids being the main contributing prey taxa to these differences (Figure 14). Round goby and spottail shiner diets were the most similar at 49%.

Job 104.3: Report preparation

Data were further processed to include in Primer-E analyses. Visual representations of multivariate community analyses were generated to include in this report.

Discussion

After our second full year of sampling three locations with different habitat characteristics, it appears that mechanisms influencing fish assemblages may operate at small, localized spatial scales (i.e. <20 km). Clearly, temporal changes in the abundance of fish also occur. Qualitative differences in abiotic and biotic conditions that could influence fish growth and survival have been observed between our sampling locations. Species composition of fish and benthic invertebrates differed among locations in 2008 and 2009. Water temperature also differed among locations in early summer months. Continued monitoring is needed to build a long term data set to help determine the impact these differences may have on community composition and fish growth and survival in the Illinois nearshore waters of Lake Michigan.

There is a large data gap on fish older than YOY but younger than spawning adults, and for fish communities on rocky habitats (Keast 1977; Vanderploeg et al. 2002). Within lakes, different fish assemblages are found among habitat types (Pratt and Smokorowski 2003). Using identical sampling gear (small-mesh gill nets) at the three locations we did find fish community differences. Dead River is the most featureless of our locations, with fine sandy substrate and no shoreline structures. Dead River is also generally colder than the other sites and subject to more frequent upwelling events. It thus makes sense that alewife, which is pelagic and prefers cool water, was more abundant at this location than at the others locations. Spottail shiners have previously been noted to spawn in water depths < 5m over sand in Lake Michigan during late June – September (Wells and House 1974). Our data also suggest this habitat type preference: spottail shiner numbers were highest overall at DR and lowest at the 7 m sites for all locations.

Habitat preference of demersal age-0 yellow perch indicates that association with rocky substrate begins within their first year of life (Janssen and Luebke 2004). Rocky substrate provides habitat for prey and refuge for yellow perch. Underwater observations indicate that small yellow perch take refuge beneath and move among rocks (Janssen and Luebke 2004). M2 is the most structurally complex of the three locations, with sand, gravel, pebble, cobble and boulder substrate and indeed, yellow perch were more abundant at M2 compared to the other two, less complex, sites. In addition to the substrate, the temperature regime at M2 likely makes this site a transition area between the relatively stable temperatures at S2 and the more variable temperatures at DR (frequent bottom temperature declines).

S2 is a mosaic of sand, pebbles, and intermittent cobble overlying clay and has a much armored shoreline. Water temperatures at all three locations were relatively cool compared to years past, but S2 does warm up quicker in the spring. Alewives were caught in low numbers at S2 in June -July; CPE was highest in August when bottom temperatures declined after upwelling. They appeared to move north to DR and M2 in September. Catches of other species at S2 fluctuated through the season and did not have strong correlations to water temperatures.

The combination of habitat complexity and prey diversity/abundance can have a large impact on juvenile fish in Lake Michigan. Age-0 yellow perch in southern Lake Michigan consume primarily amphipods, isopods, and chironomids (Pothoven et al. 2000; Janssen and Luebke 2004; Creque et al. 2007), which are associated with rocky habitat (Winnell and Jude 1987). Chironomid densities were highest at M2 and amphipods at S2, which were the locations with the highest yellow perch CPE. Thus, it is very likely that the availability of rocky substrate influences not only spawning success of adults, but also habitat selection of yellow perch during their first year of life. Pelagic fish such as alewife and young salmonids may be attracted to rocky areas to feed during invertebrate emergences (Janssen and Luebke 2004); we did observe chironomids in some alewife stomachs.

Analyses of June and July, 2008 fish diets demonstrated that regardless of location, diets within species were very similar in early summer and there was no apparent overlap between species. This is different from feeding patterns during August - October that showed diet similarity between the invasive round goby and native yellow perch and spottail shiners (Creque and Czesny 2009). These fish consumed small benthic zooplankton and invertebrates in August and switched to larger benthic invertebrates in September and October. If abundance of these benthic organisms further declines, the round goby would be at a competitive advantage because of their ability to consume Dreissenid mussels. Yellow perch would likely be impacted more than spottail shiner because both yellow perch and round goby were most abundant at the rockier sites whereas spottails shiners were more common in sandy locations. Additional years of data collection will give us further insight into the competitive interactions of these species in Lake Michigan. We will also be able to compare stomach contents of fish to zooplankton composition and benthic invertebrate assemblages and determine if diet shifts occur because of changes in food preference or shifts in food availability. For example, Keast and Eadie (1985) determined that differences in growth of juvenile largemouth bass in the same system were due to differences in diet caused by prey availability.

There is a limited understanding of the importance of various factors affecting fish communities in nearshore waters of Lake Michigan. Since the arrival of the invasive zebra mussel, quagga mussel, and round goby, we are not sure to what extent these organisms displaced native fish to less suitable habitats, affected abundance of preferred prey of native fish, and impacted growth of native fish species. Our data shows that these invasive species were primary contributors to community differences within our study area. While populations of alewife have declined, round goby have expanded into the north sampling area in recent years. Yellow perch growth has been declining compared to that in the late 1990s and young round gobies consume many of the same benthic species as juvenile yellow perch.

Identifying and understanding ecological constraints placed on yellow perch year-class strength and growth is critical for harvest regulations and habitat protection. Similarly, understanding alewife dynamics is important because these planktivores are the primary food source of stocked salmonids in Lake Michigan (Stewart et al. 1981). Information on alewife abundances and growth will indicate appropriate salmonid stocking levels, and may be useful to predict negative interactions between yellow perch and alewife. Extending our knowledge on other species such as bloaters *Coregonus hoyi*, Cyprinids, round goby, and rainbow smelt will provide additional information on the prey base for adult sport fishes, and a more complete picture of competitive interactions within the nearshore fish assemblage. Overall understanding of how abundance, composition, growth and competition within the nearshore fish communities relate to habitat, food availability, and temperature will be very beneficial to managers as they work to set angler harvest limits, salmonid stocking quotas, and preferred areas for habitat protections and/or restoration.

Conclusions

Current management strategies for Lake Michigan focus on nearshore waters as contiguous units despite many habitat differences exhibited in this study at three different habitat types. Therefore, it is important to continue to investigate how ecological conditions vary temporally and within smaller spatial scales in the nearshore zone, and effects these differences (e.g., temperature, food resources, and habitat structure) may have on growth, survival, and species composition of the entire nearshore fish assemblage.

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Table 1. Length characteristics (mean length in mm ± 1 standard deviation, range of lengths, and number of fish measured in parentheses) of fish caught in small-mesh gill nets at three locations along the Illinois shoreline of Lake Michigan during June through September, 2009. One number indicates the length of the only fish that was measured.

Fish	Location	June	July	August	September
YELLOW PERCH	DR		118.4 ± 23.3 72-152 (16)		88.1 ± 30.1 52-196 (101)
	M2	118.5 ± 12.7 74-141 (24)	126.2 ± 34.5 78-209 (34)	63.0 ± 12.9 53-113 (60)	100.9 ± 21.1 56-132 (37)
	S2	162.7 ± 24.8 126-205 (13)	153.7 ± 36.9 98-230 (34)	125.7 ± 28.4 57-180 (21)	71.3 ± 13.2 57-146 (39)
ALEWIFE	DR	90.9 ± 17.6 68-161 (133)	98.2 ± 24.2 72-169 (38)	136 ± 28.3 110-169 (4)	86.5 ± 12.0 59-107 (41)
	M2	112.5 ± 20.6 93-134 (3)	108.6 ± 19.6 76-150 (22)	118.1 ± 9.8 101-154 (53)	90.8 ± 4.1 84-98 (33)
	S2	76.9 ±7.0 70-99 (15)	115.3 ± 19.5 80-163 (23)	110.8 ± 16.5 56-134 (41)	
SPOTTAIL SHINER	DR	103.4 ± 10.3 85-120 (16)	104.2 ± 10.6 92-124 (22)	114.1 ± 2.4 111-116 (3)	113 ± 10.2 87-132 (60)
	M2		112.5 ± 7.9 93-126 (23)	110	99.1 ± 5.0 92-112 (19)
	S2	105.9 ± 11.9 87-120 (11)	91.2 ± 18.6 54-109 (23)		95.9 ± 4.9 91 – 101 (3)
ROUND GOBY	DR	93.2 ± 2.3 92-95 (2)	86.1 ± 9.8 77-103 (6)		77.1 ± 12.0 48-120 (65)
	M2	72.2 ± 12.1 58 – 116 (75)	65.3 ± 8.5 43-82 (46)	68.8 ± 8.6 57-81 (10)	66.1 ± 11.5 50-101 (38)
	S2	76.5 ± 9.9 52-102 (36)	71.9 ± 11.2 45 -97 (69)	69.4 ± 8.4 62-84 (9)	65.2 ± 8.4 62 – 78 (4)

Table 2. Mean length (mm) ± 1 standard deviation of the fish captured in small-mesh gill nets in June and July 2008 whose stomachs were processed for diet analysis.

Fish	Mean length ± 1 stdv	Number of stomachs
yellow perch	104.9 ± 31.8	48
alewife	121.+9 ± 16.7	86
spottail shiner	106.3 ± 7.0	10
round goby	77.8 ± 18.2	112

Table 3. Annual mean total benthic invertebrate density (#/m^2) ± 1 standard deviation in core samples at each location by depth for June – October sampling in 2009. Number in parentheses equals the number of core samples collected.

Site depth/Location	DR	M2	S2	All locations combined
3 m	379 ± 324 (12)	816 ± 745 (11)	852 ± 678 (16)	697 ± 636 (39)
5 m	916 ± 457 (12)	3132 ± 3484 (12)	1102 ± 1574 (16)	1656 ± 2324 (40)
7 m	327 ± 128 (8)	4667 ± 1822 (12)	6690 ± 7900 (16)	4602 ± 5828 (36)

Table 4. Total number of organisms detected on rocks collected at M2 and S2 during the 2009 sampling season. Number in parentheses is the number of rocks collected at each location.

General Category	**Taxa**	**M2 (20)**	**S2 (14)**
Amphipods	Amphipoda	9	57
	Diaporia hoyi	1	
	Echinogammarus	3	148
	Gammaridae	11	185
	Gammarus	1	
	Hyalella azteca	40	
Midges	Chironomid larva	1377	198
	Chironomid emerging	1	
	Chironomid pupal	24	8
Non-native mussels	Pelecypoda	1100	2113
	Dreissena bugensis	654	807
	Dreissena polymorpha	15	13
Gastropods	Gastropoda	7	
	Hydrobiidae	5	
	Valvatidae	13	
	Viviparidae	7	
Arachnid	Halacaridae	3	
	Hydracarnia	73	32
	Oribatei	3	1
Benthic Zooplankton	Chydoridae	181	1
	Harpacticoida	207	194
Mayfly	Heptageniidae	3	
	Stenacron	7	
Misc. invertebrates	Isopoda	28	
	Nematoda	193	748
	Oligochaete	1460	184
	Ostracoda	6	1
	Tardigrada	81	7
	Coleoptera	2	
	Platyhelminthes	1	
Total number		5537	4713

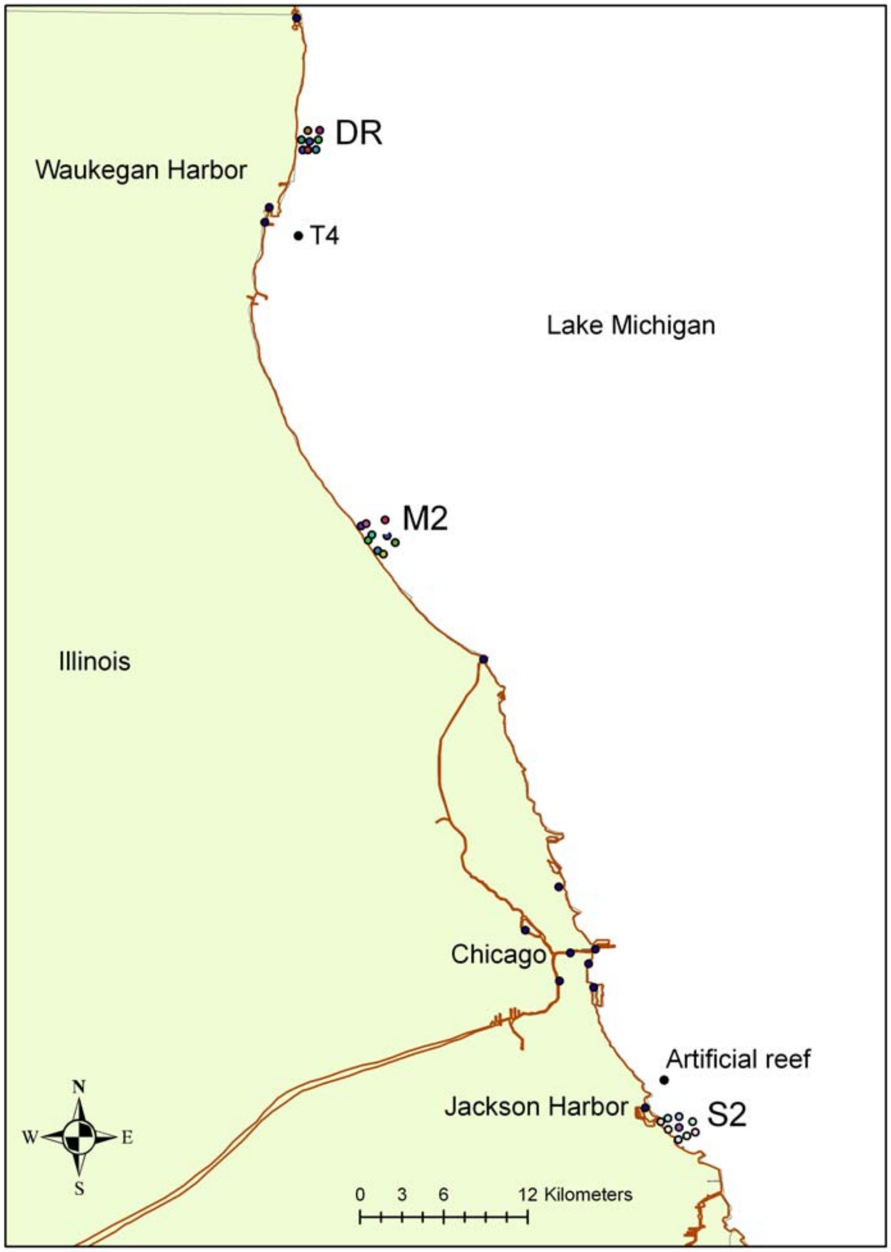


Figure 1. Map of sampling locations in the Illinois waters of Lake Michigan.

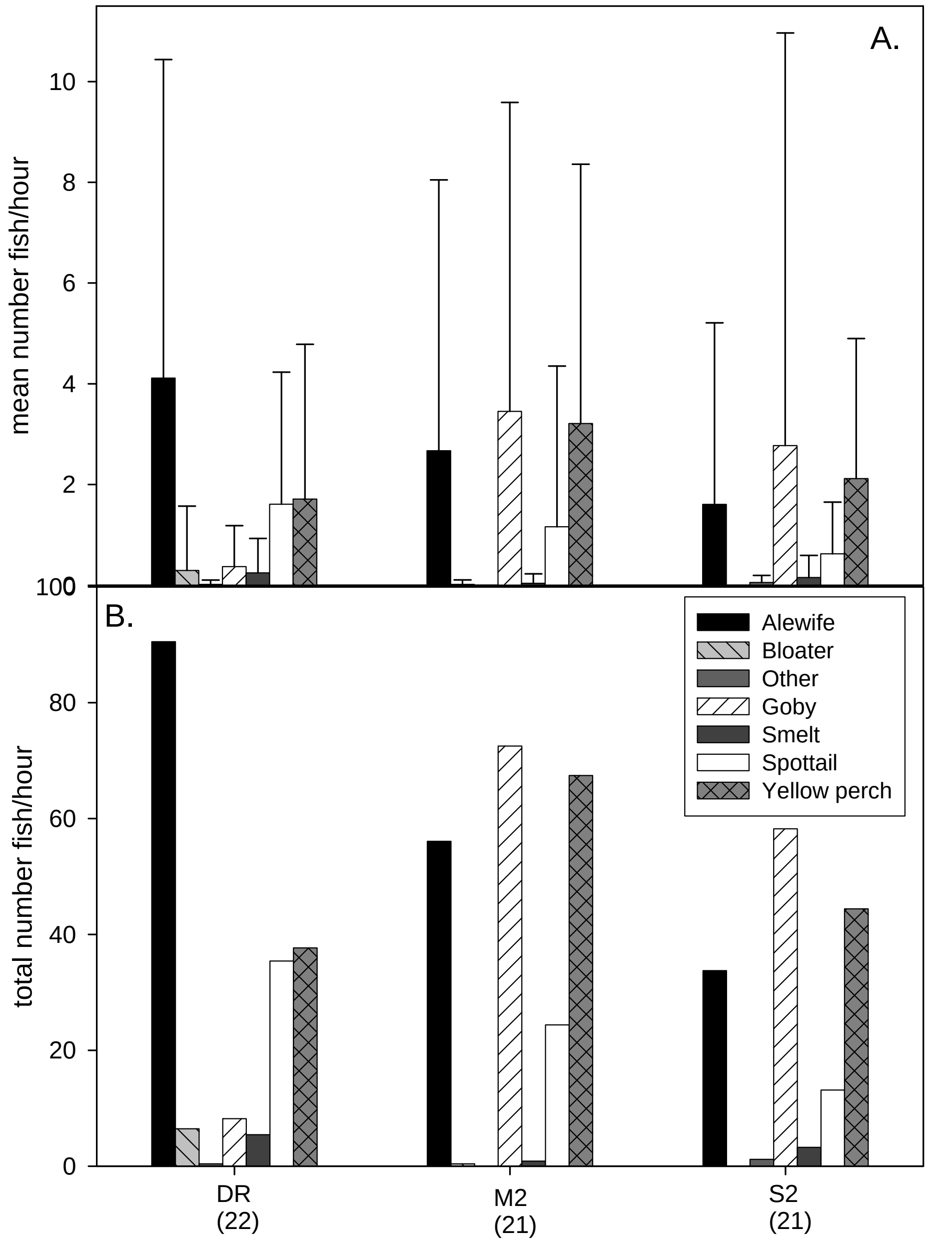


Figure 2. Small-mesh gill net annual catch per unit effort in (A) mean number of fish per hour and (B) total number of fish per hour at three locations in Illinois waters of Lake Michigan during June – September, 2009.

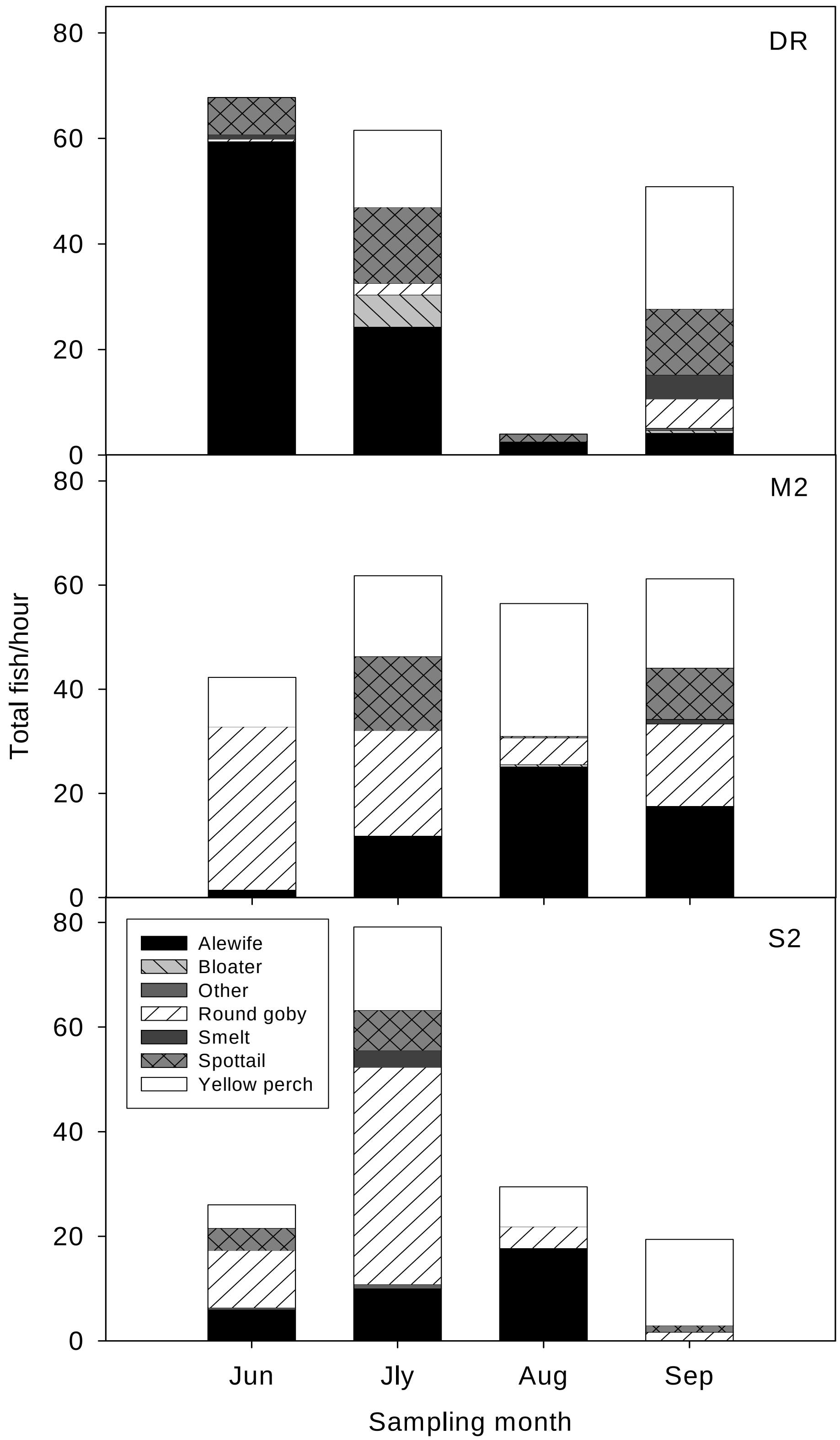


Figure 3. Monthly catch per unit effort (total fish/hour) by fish species at three locations in southwestern Lake Michigan.

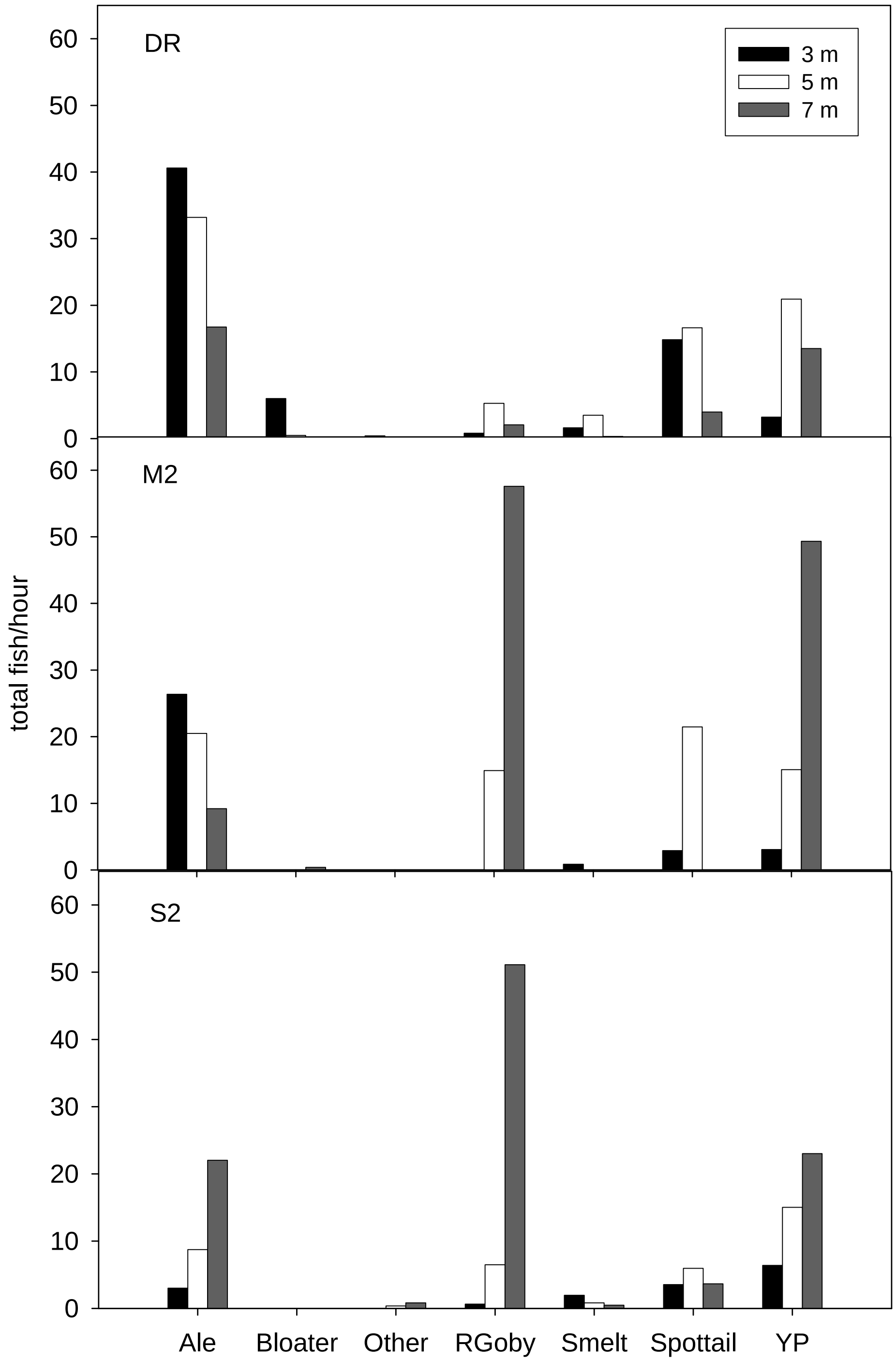


Figure 4. Annual total number of fish per hour in small mesh gill nets set at three water depths (3, 5 and 7 meters) at each of three locations (DR, M2, and S2).

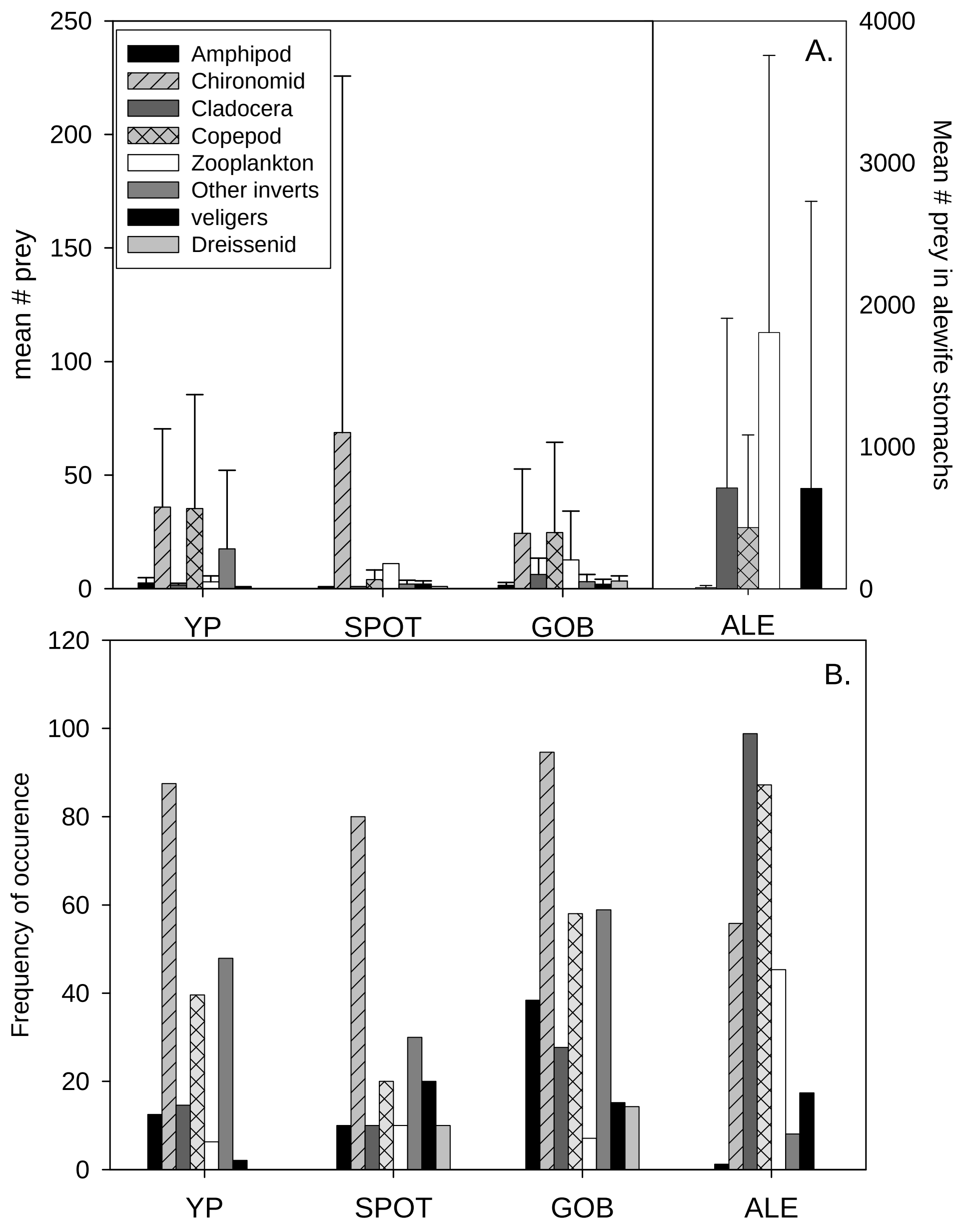


Figure 5. Diet information for the most commonly caught fish species in small-mesh gill nets at all locations combined during June and July, 2008: (A) mean number of prey items in individual stomachs and (B) frequency of occurrence of each prey item. YP = yellow perch, ALE = alewife, SPOT = spottail shiner, GOB = round goby.

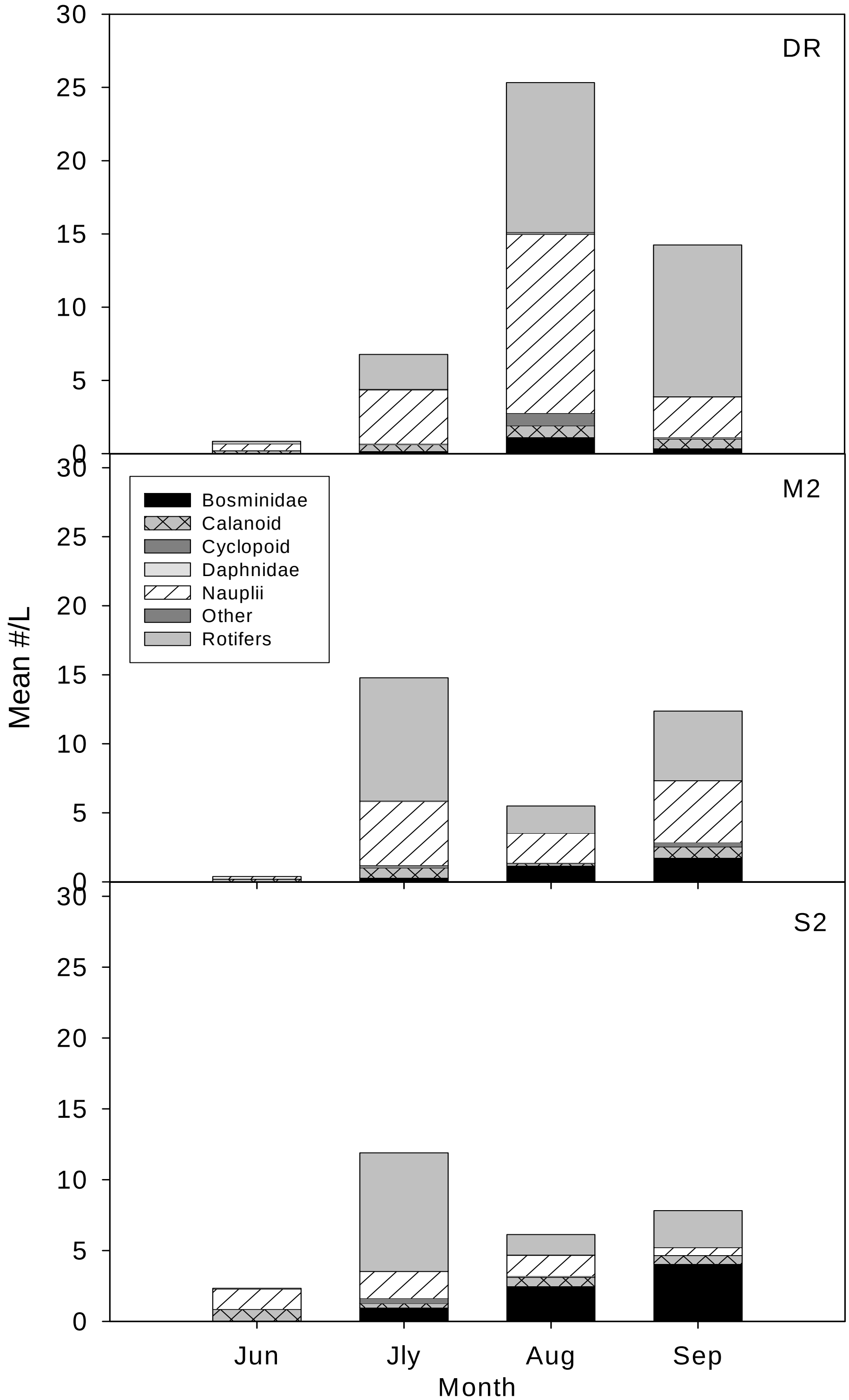


Figure 6. Monthly mean zooplankton density (#/L) for the most common taxa collected at three locations in Illinois waters of Lake Michigan during 2009.

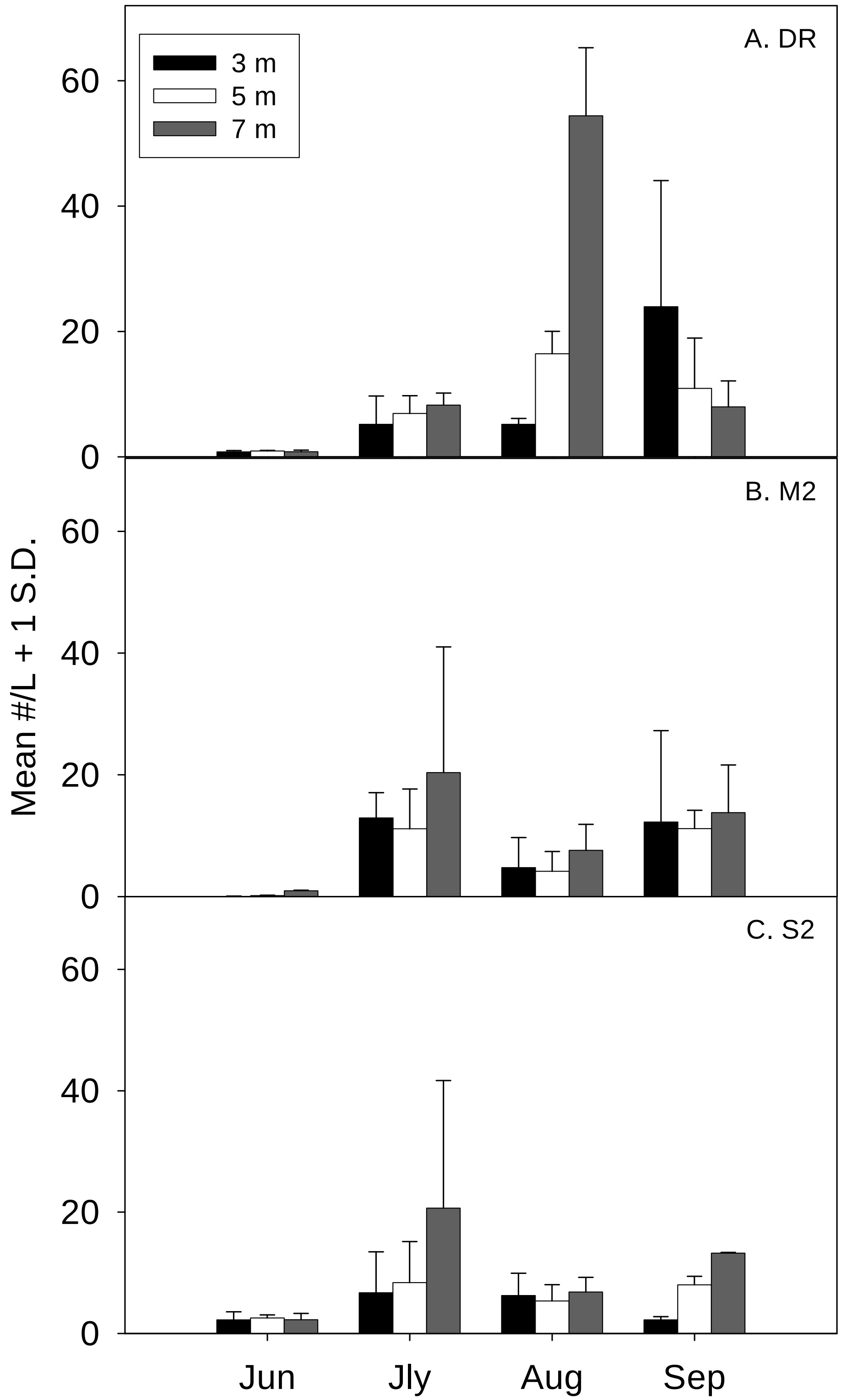


Figure 7. Monthly mean zooplankton density (#/L + 1 S.D.) by water depth at three nearshore locations in Illinois waters of Lake Michigan.

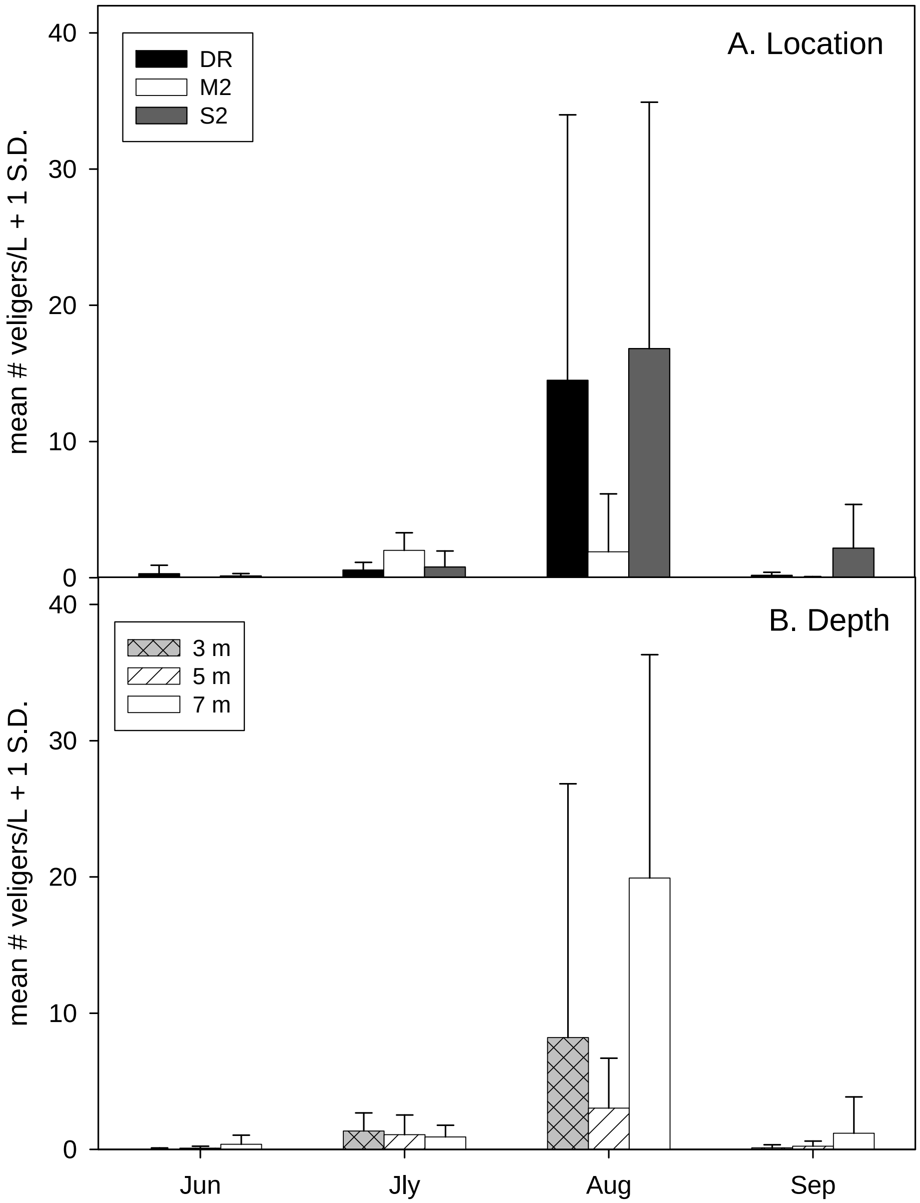


Figure 8. Monthly mean number of Dreissenid veligers (#/L + 1 S.D.) by (A) location and (B) water depth during 2009.

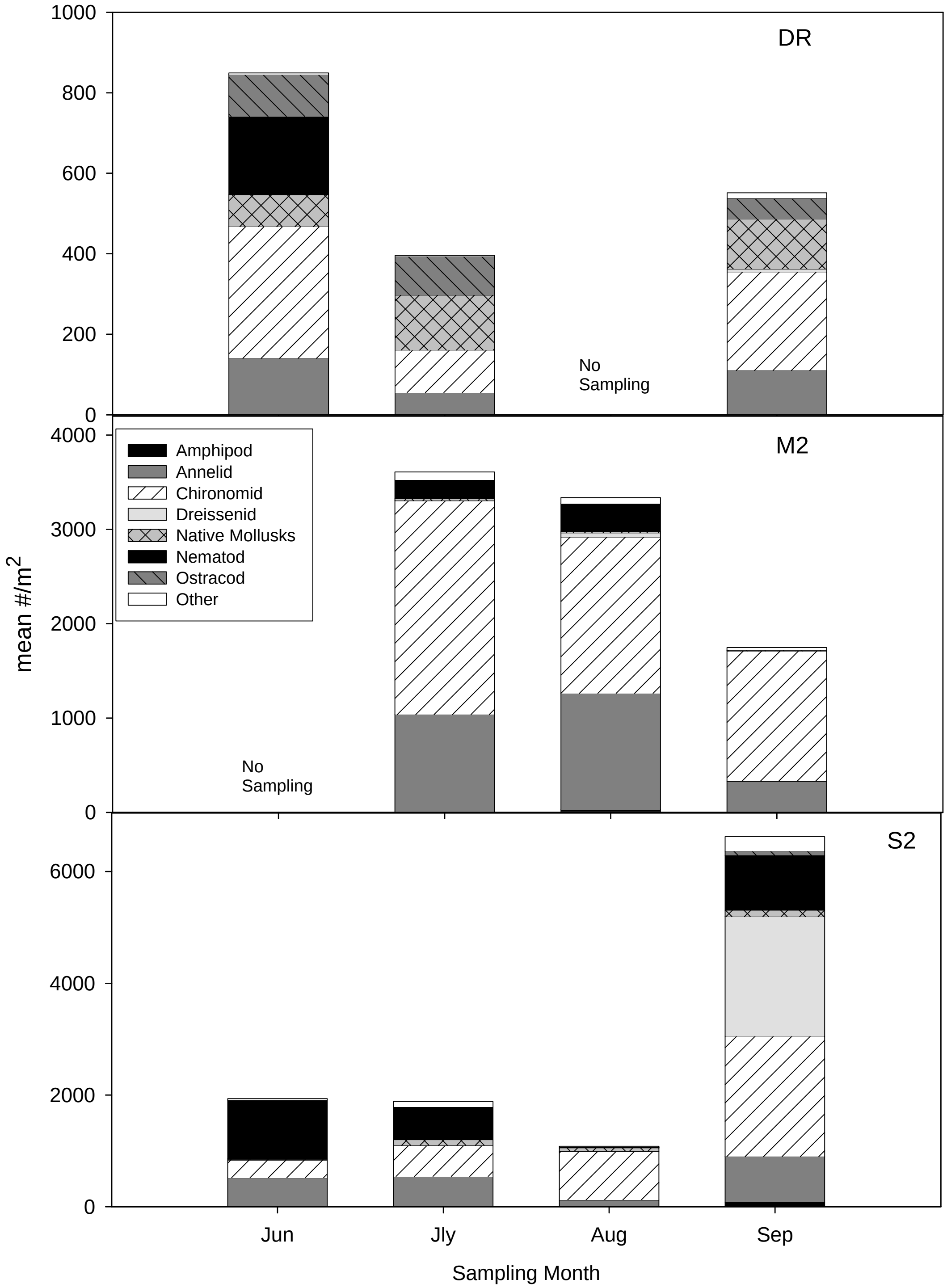


Figure 9. Monthly mean density (#/m^2) of the most common invertebrate taxa collected in benthic cores during 2009 sampling.

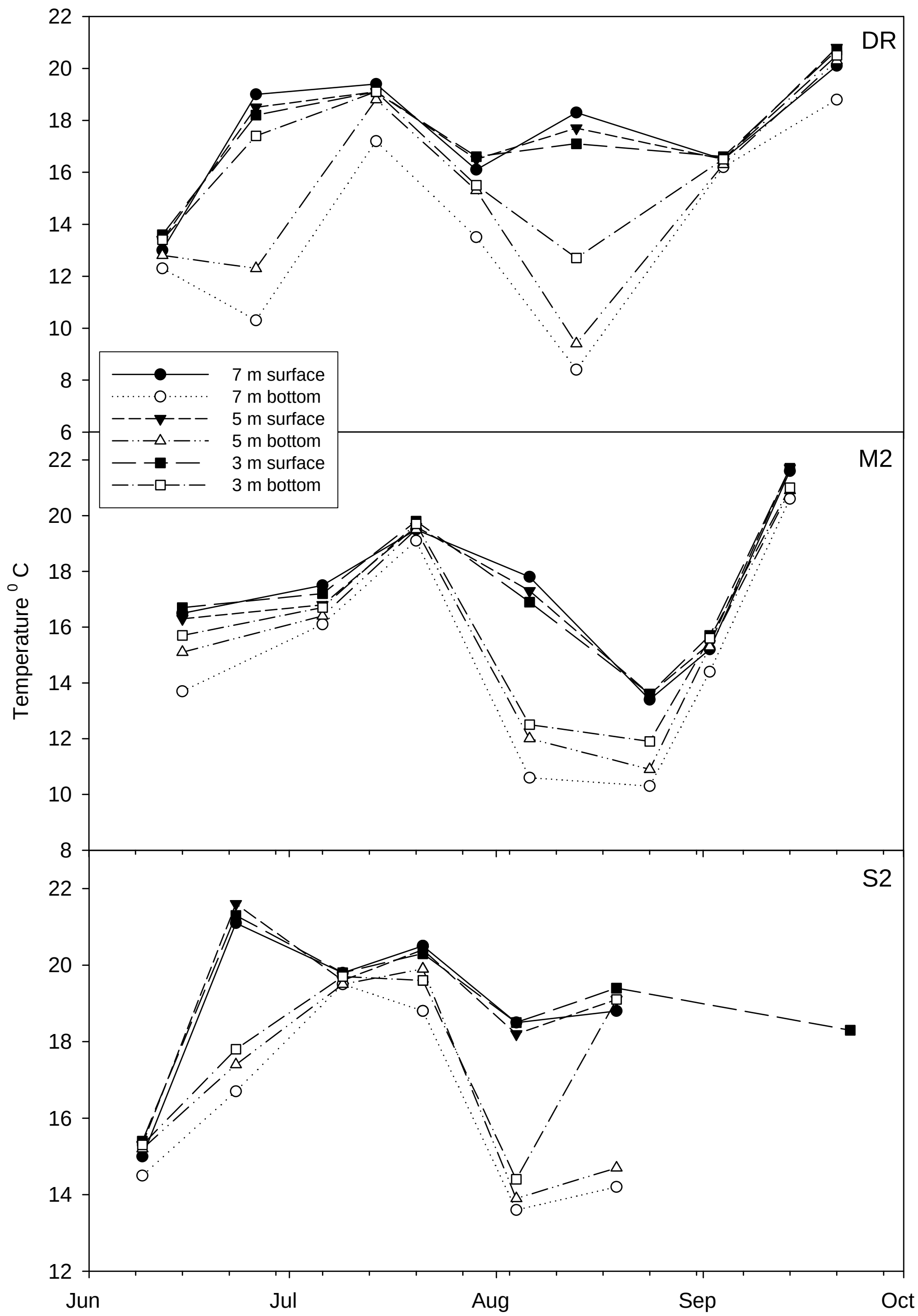
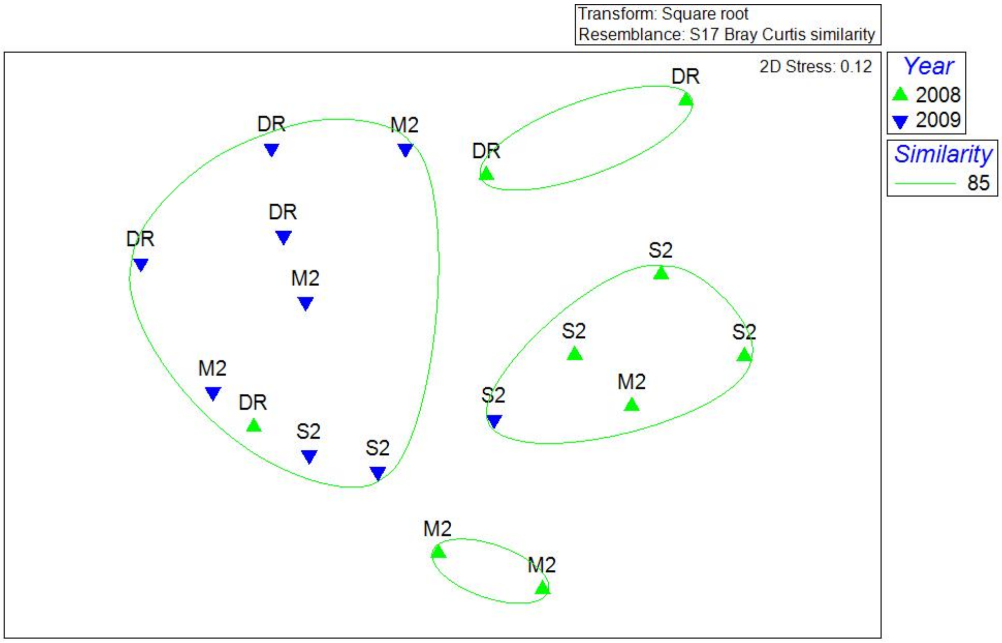


Figure 10. Surface and bottom water temperatures from profiles taken on each sample outing during 2009.



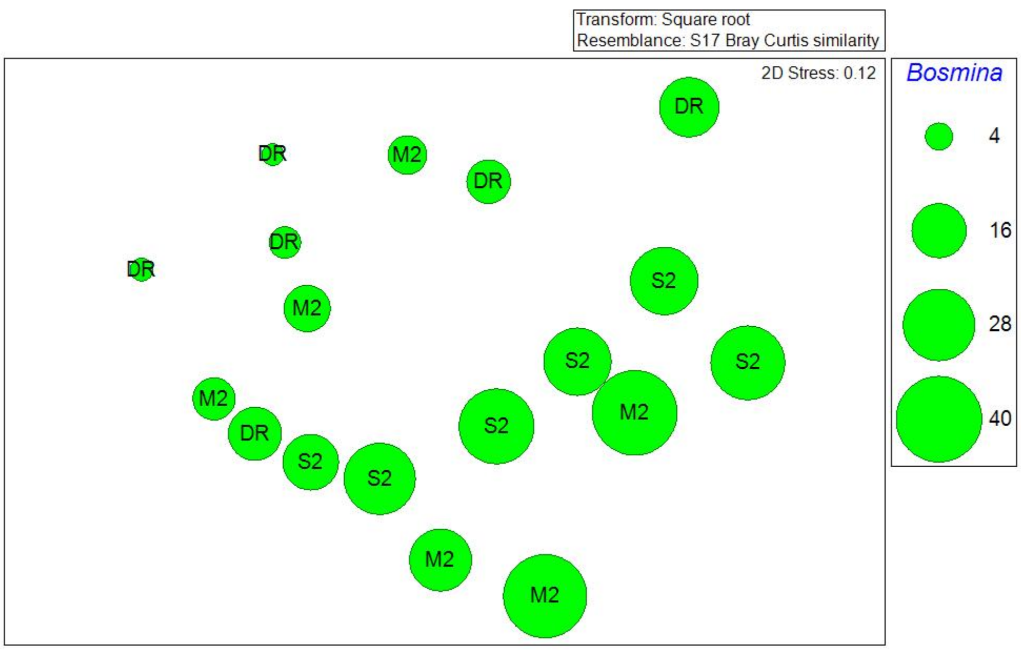


Figure 11. Non-metric multidimensional scaling plot for zooplankton composition (% by number) of the nine location/site combinations sampled in 2009; text above symbols indicate location. Symbols that are close together have greater similarity in diet than symbols that are further apart; connecting lines indicate groups with 85% community similarity from cluster analysis. Lower panel has superimposed circles whose varying diameters reflect abundance changes for Bosminidae across the groups.

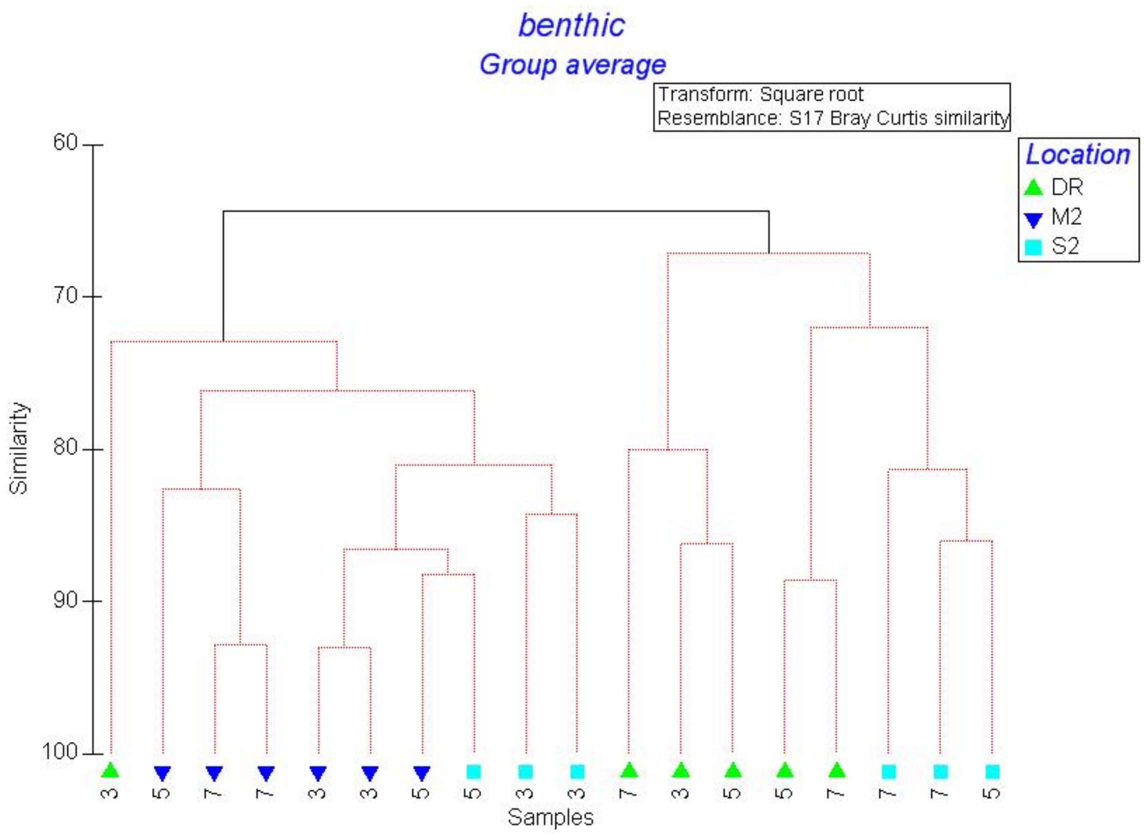


Figure 12. Cluster analysis for invertebrate composition (% by number) in cores for the nine location/site combinations sampled in 2009; numbers below symbols indicate site depth.

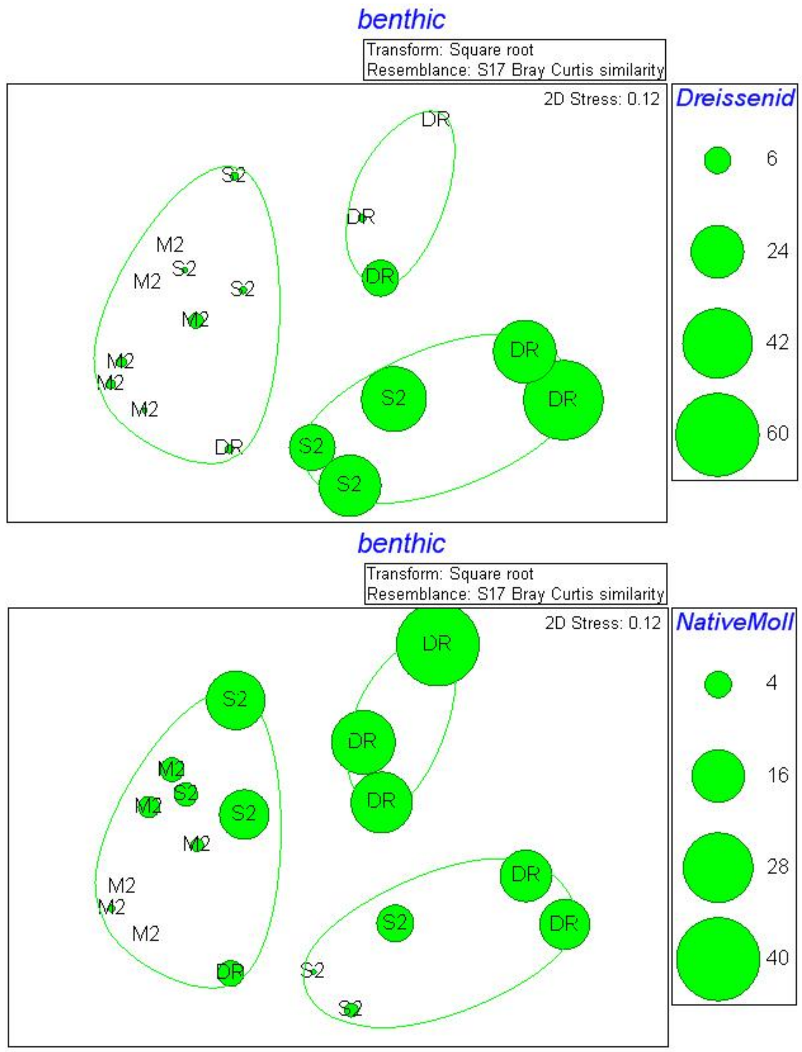
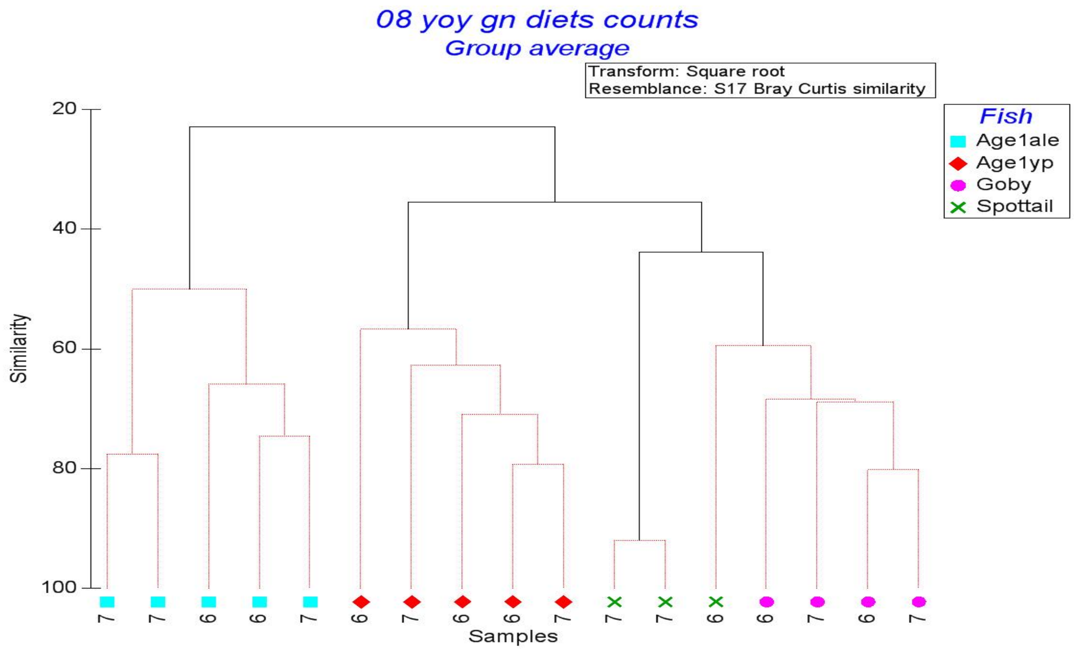


Figure 13. Non-metric multidimensional scaling (NMDS) plot for invertebrate composition (% by number) in cores for the nine location/site combinations sampled in 2009. Symbols that are closer together have greater similarity in diet than symbols that are further apart. The superimposed circles varying diameters reflect abundance changes for invasive dreissenids and native molluscs across the groups.



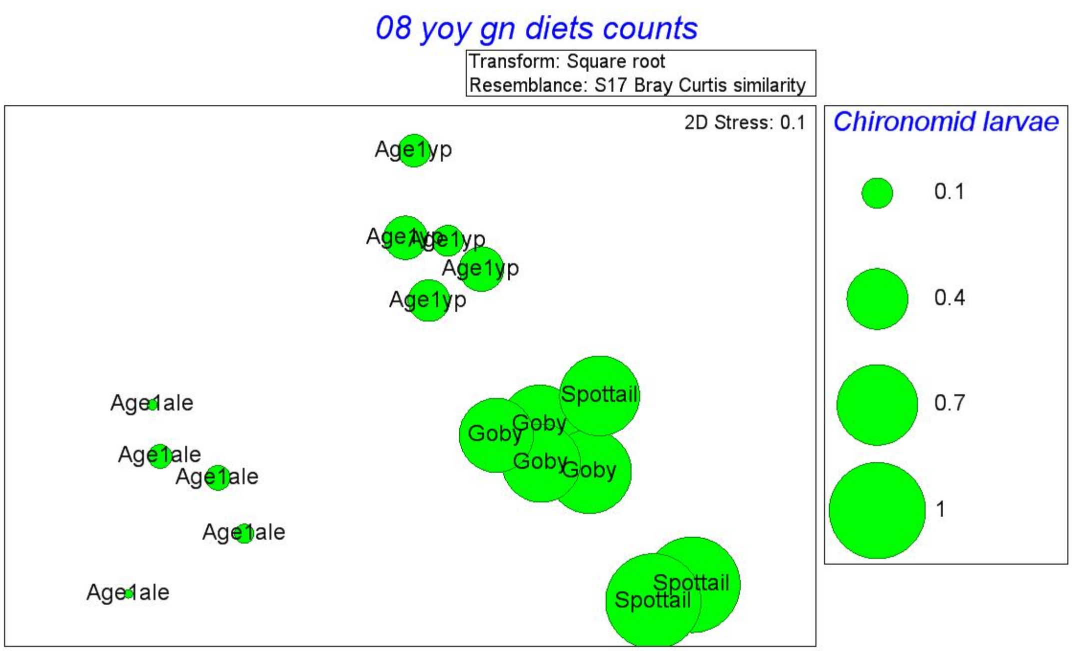


Figure 14. Cluster analysis for diet composition (% by number) of alewife, yellow perch, round goby and spottail shiner collected in small-mesh gill nets during June and July, 2008 and non-metric multidimensional scaling plot with superimposed circles whose varying diameters reflect abundance changes for chironomid larvae.